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FIG. 1

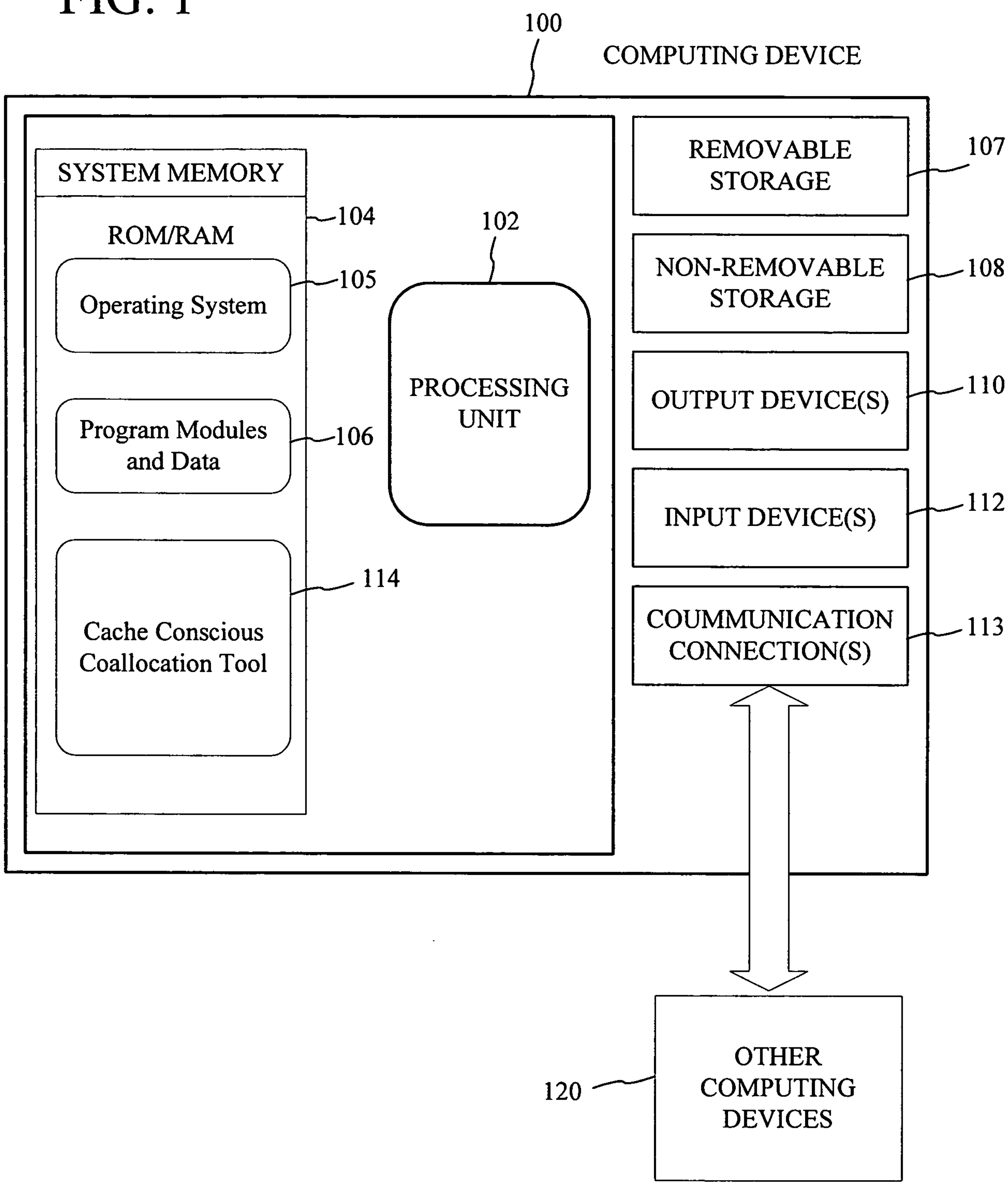

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FIG. 2A

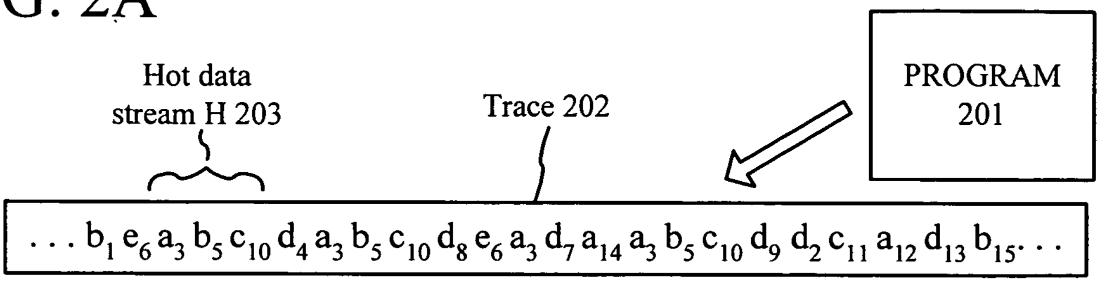

FIG. 2B

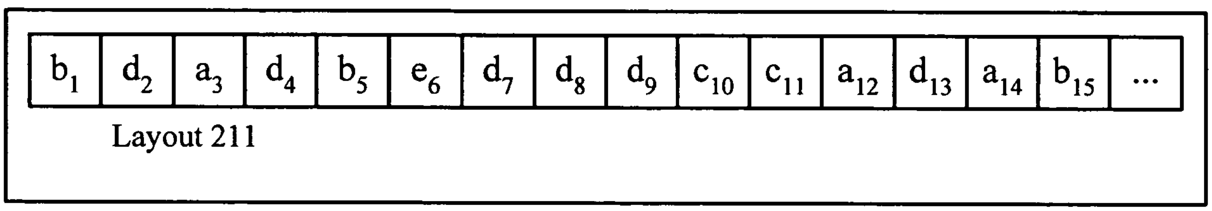

FIG. 2C

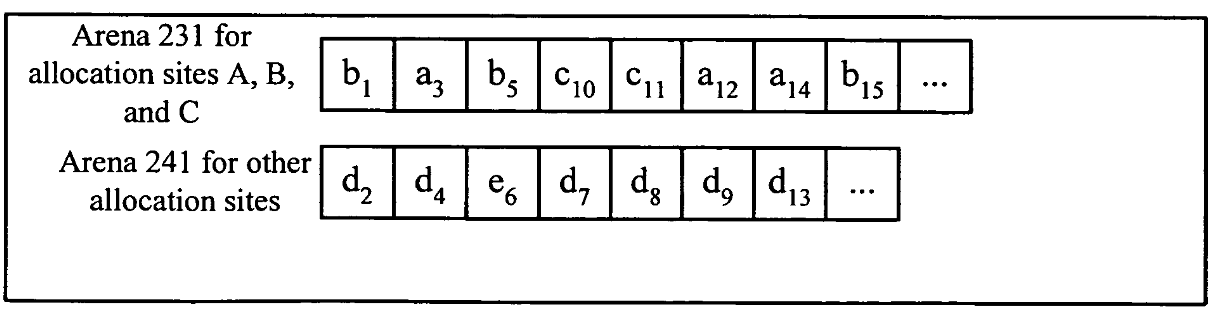

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FIG. 3A

ht	stream	coallocatable objects	mr	coallocation set	w'
0.6	$a_3b_5c_{10}$	a_3, b_5	1	{A, B}	0.6
		a_3, c_{10}	1	{A, C}	0.6
		b_5, c_{10}	1	{B, C}	0.6
		a_3, b_5, c_{10}	2	{A, B, C}	1.2
0.3	$d_4b_{15}e_6$	b_{15}, e_6	1	{B, E}	0.3
		d_4, e_6	1	{D, E}	0.3
0.1	$d_4e_6a_{12}a_{14}$	d_4, e_6	1	{D, E}	0.1
		e_6, a_{12}	1		
		e_6, a_{14}	1		
		a_{12}, a_{14}	1	{A}	0.1
		e_6, a_{12}, a_{14}	2	{A, E}	0.2

FIG. 3B

coallocation set	accumulated miss reduction	normalized miss reduction
{A,B}	0.6	0.29
{A,C}	0.6	0.29
{B,C}	0.6	0.29
{A,B,C}	1.2	0.57
{B,E}	0.3	0.14
{D,E}	0.4	0.19
{A,E}	0.2	0.1
{A}	0.1	0.05

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FIG. 3C

	set packing	miss reduction
1	{A,B,C}, {D,E}	0.76
2	{A,B}, {D,E}, {C}	0.48
3	{A,C}, {D,E}, {B}	0.48
4	{A,C}, {B,E}, {D}	0.43
5	{A,E}, {B,C}, {D}	0.38
8	{A}, {B,C}, {D,E}	0.52
9	{A}, {B,E}, {C,D}	0.19

FIG. 3D

Coallocation layout for set packing 1

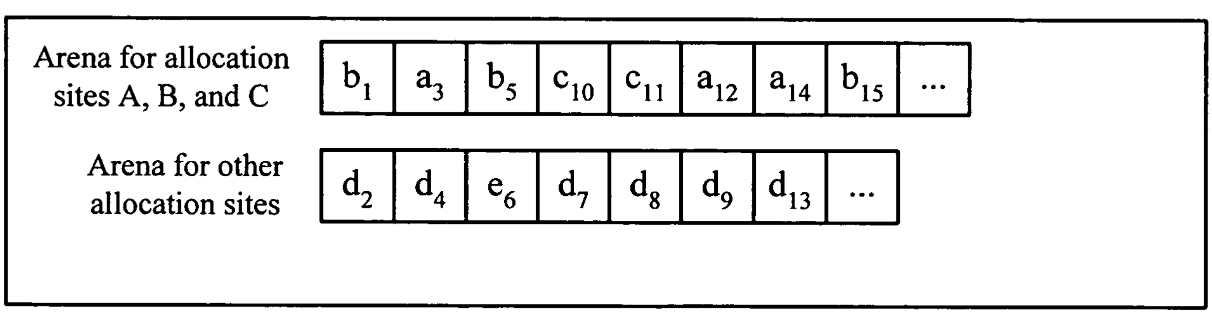

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FIG. 4

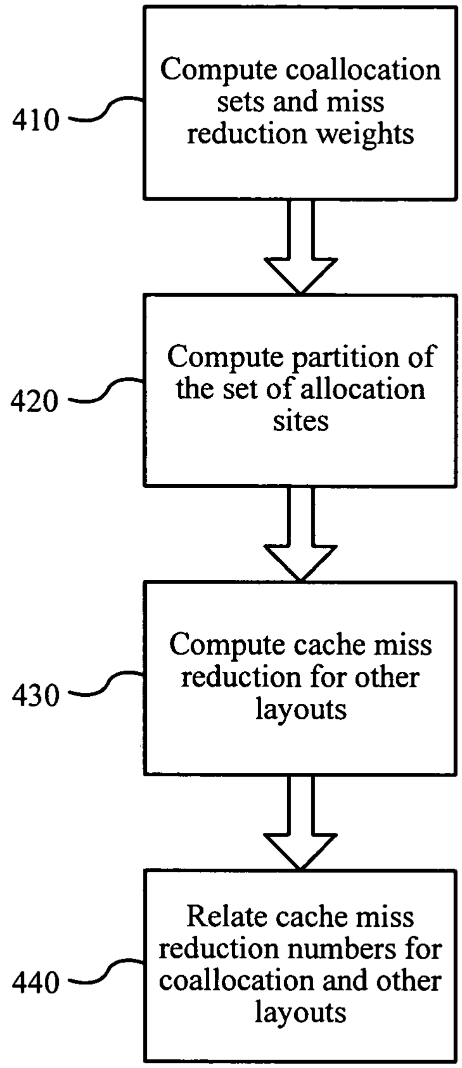

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FIG. 5A

```
// first phase: compute cache miss reduction weights for coallocation sets.
// The parameter object coallocatable communicates the criteria for coallocating objects,
// and the criteria may vary with different coallocatability definitions.
computeWeight(object coallocatable, w)

// second phase: compute approximated weighted set packing according to Halldórsson's
// algorithm, where Π is the set of hot data streams and Π_WSP is a partition of S_alloc(Π)
// with approximated maximal cache miss reduction.
Π_WSP = WSP(S_alloc(Π), {⟨C, w(C)⟩ | w(C) > 0})
R_o = Σ_{C∈Π_WSP} w(C)
output Π_WSP

// third phase: compute cache miss reduction for a given layout, and then normalize weights.
for every H ∈ Π
        w_total = w_total + (|H| - 1) * heat(H)
        // C is a set of coallocatable objects.
        C = ø
        loop a ∈ H according to layout order
                if objects in C ∪ a are laid out contiguously
                        C = C ∪ a
                else
                        w_l = w_l + (|C| - 1) * heat(H)
                        C = {a}
R_l = w_l/w_total

// fourth phase: relate (sub)optimal coallocation and the given layout cache miss reduction numbers.
R_l^o = (R_o - R_l)/(1 - R_l)
output R_l^o
```

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FIG. 5B

```
// Get cache miss reduction for coallocation sets, where Π is the set of hot data streams, and
// heat(H) gives the normalized heat of H.  Coallocatable expresses the coallocatability criteria.
computeWeight(coallocatable, w)
    for H ∈ Π
        w_total = w_total + (|H| - 1) * heat(H)

        // compute weights for coallocation sets corresponding to subsets of H.
        for H' ⊆ H
            if objects in H' are coallocatable
                w'(H') = (|H'| - 1) * heat(H)
            else
                w'(H') = 0

        // attribute weights for coallocation sets avoiding double contributions,
        // by computing the maximal partition contribution for a coallocation set.
        for each coallocation set C
            P = {H'_i | w'(H'_i) > 0 ∧ S_alloc(H'_i) = S_alloc(H'_j) ∧ H'_i ⊂ H'_j ⇒ w'(H'_j) = 0}
            w'(C) = Σ_{H'_i ∈ P} w'(H'_i)

    // normalize weights.
    for each coallocation set C
    w(C) = w'(C)/w_total
```

$$P = \{H_i^{'} \mid w'(H_i^{'}) > 0 \wedge S_{alloc}(H_i^{'}) = S_{alloc}(H_j^{'}) \wedge H_i^{'} \subset H_j^{'} \Rightarrow w'(H_j^{'}) = 0\}$$

$$w'(C) = \sum_{H_i^{'} \in P} w'(H_i^{'})$$

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FIG. 6

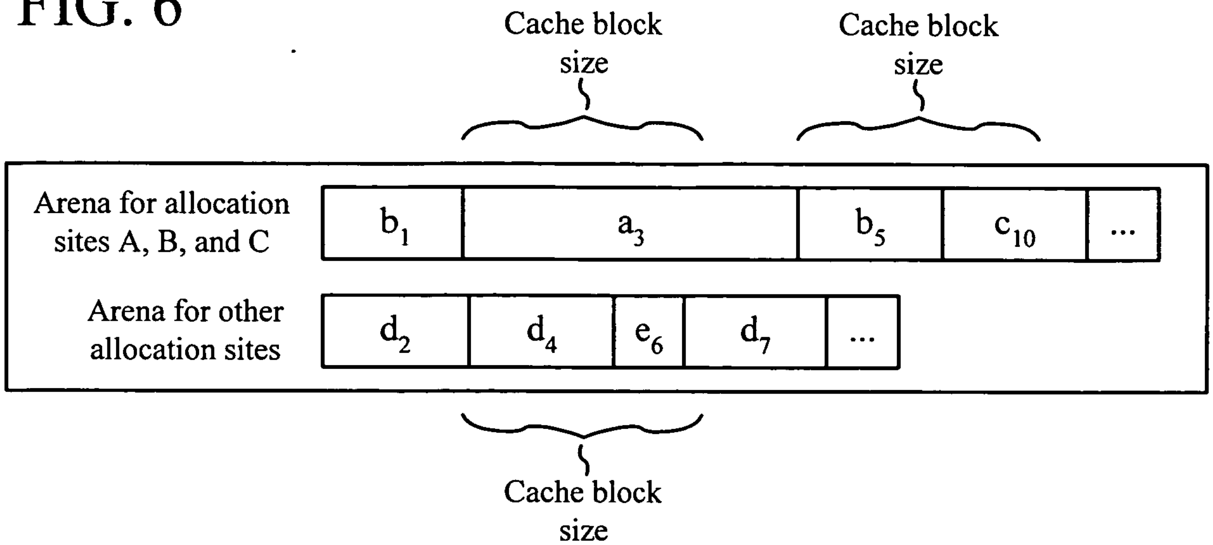

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FIG. 7A

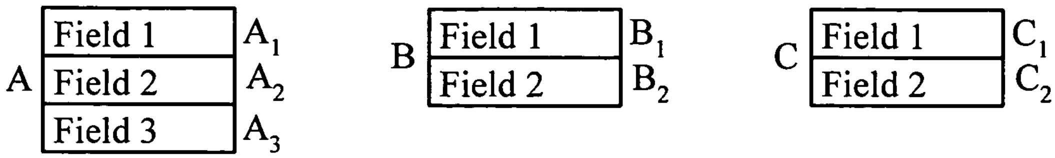

FIG. 7B

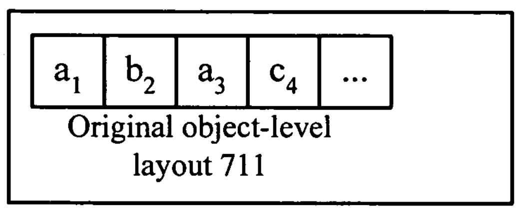

FIG. 7C

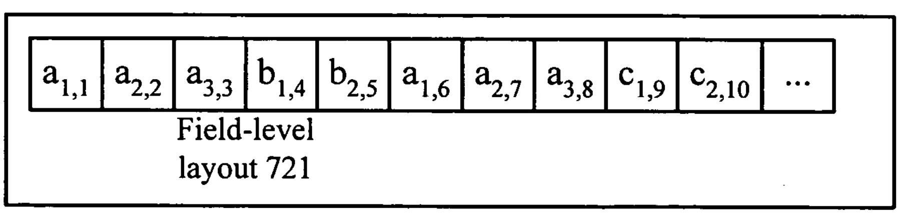

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FIG. 7D

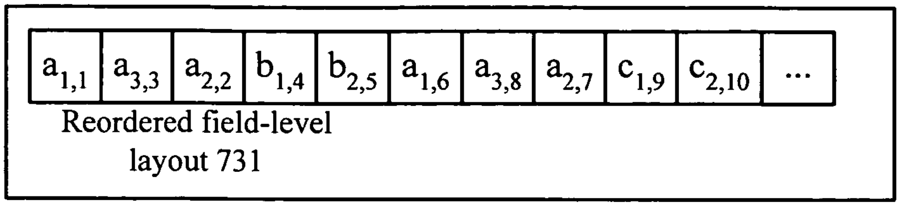

FIG. 7E

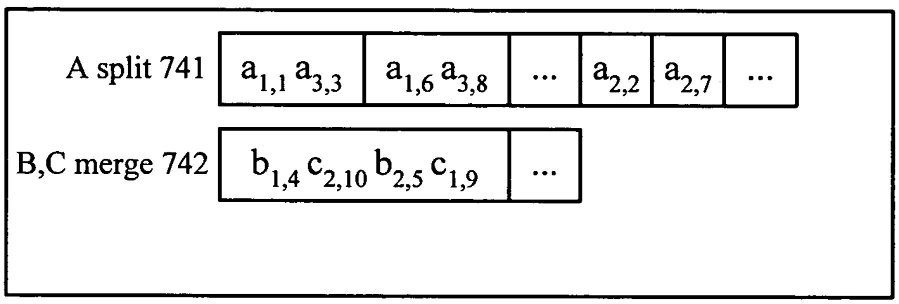

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FIG. 8

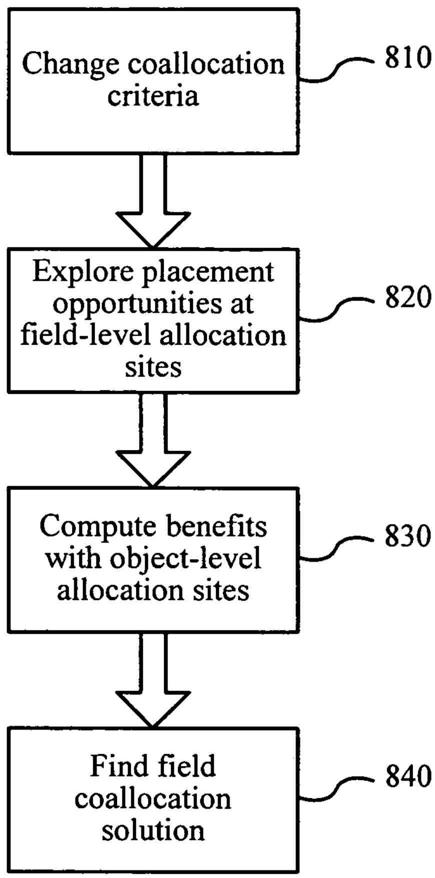

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FIG. 9A

// first phase: compute normalized weights for fields coallocation sets according to reorder,
// split, and merge coallocation conditions. The routine computeWeight is given above.
computeWeight(field reorder coallocatable, w_r)
computeWeight(object split coallocatable, w_s)
computeWeight(object merge coallocatable, w_m)

// second phase: approximate benefits for every placement technique at the granularity of object
// allocation sites. $OBJ(X_i)$ gives the object allocation site for a given field allocation site,
// i.e., $OBJ(X_i) = X$. We also extend OBJ to sets of field allocation sites.
for each object coallocation set $\mathcal{C}$
    if $|\mathcal{C}| = 1$ // compute split + reorder benefits.
        $\mathcal{C}_{rWSP} = WSP(\mathcal{C}, \{\langle C, w_r(C)\rangle | OBJ(C)=\mathcal{C}\})$
        $w_r(\mathcal{C}) = \sum_{C \in \mathcal{C}_{rWSP}} w_r(C)$
        $w_m(\mathcal{C}) = w_r(\mathcal{C})$
        $\mathcal{C}_{sWSP} = WSP(\mathcal{C}, \{\langle C, w_s(C)\rangle | OBJ(C)=\mathcal{C}\})$
        $w_s(\mathcal{C}) = \sum_{C \in \mathcal{C}_{sWSP}} w_r(C)$
        $w_{s \vee m} = \max(w_r(\mathcal{C}), w_c(\mathcal{C}))$
    else // $|\mathcal{C}| > 1$ merge candidates.
        $\mathcal{C}_{mWSP} = WSP(\mathcal{C}, \{\langle C, w_m(C)\rangle | OBJ(C)=\mathcal{C}\})$
        $w_m(\mathcal{C}) = \sum_{C \in \mathcal{C}_{mWSP}} w_m(C)$
        $w_{s \vee m}(\mathcal{C}) = w_m(\mathcal{C})$

to Figure 9B

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FIG. 9B

from Figure 9A

⇩

// third phase: find field coallocation solutions and show potential benefit over a given //layout. R_l is potential cache miss reduction for a given layout.

$\hat{\Pi}_{rWSP} = WSP(OBJ(S_{alloc}(\Pi)), \{\langle \hat{C}, w_r \rangle \mid w_r(\hat{C}) > 0\})$

$R_l^r = (\sum_{C \in \hat{\Pi}_{rWSP}} w_r - R_l)/(1 - R_l)$

$\hat{\Pi}_{sWSP} = WSP(OBJ(S_{alloc}(\Pi)), \{\langle \hat{C}, w_s \rangle \mid w_s(\hat{C}) > 0\})$

$R_l^s = (\sum_{C \in \hat{\Pi}_{sWSP}} w_s - R_l)/(1 - R_l)$

$\hat{\Pi}_{mWSP} = WSP(OBJ(S_{alloc}(\Pi)), \{\langle \hat{C}, w_m \rangle \mid w_m(\hat{C}) > 0\})$

$R_l^m = (\sum_{C \in \hat{\Pi}_{mWSP}} w_m - R_l)/(1 - R_l)$

$\hat{\Pi}_{s \vee m WSP} = WSP(OBJ(S_{alloc}(\Pi)), \{\langle \hat{C}, w_{s \vee m} \rangle \mid w_{s \vee m}(\hat{C}) > 0\})$

$R_l^{s \vee m} = (\sum_{C \in \hat{\Pi}_{s \vee m WSP}} w_{s \vee m} - R_l)/(1 - R_l)$

output $R_l^r, R_l^s, R_l^m, R_l^{s \vee m}$

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FIG. 10A

$H_1 = a_{1,1}\, a_{3,3}\, a_{1,6}\, a_{3,8}$ $H_2 = a_{2,2}\, b_{1,4}\, c_{2,10}$

ht	stream	coallocatable object fields	mr	coallocation set	w'
0.8	H_1	$a_{1,1}, a_{3,3}$ (R)	1	$\{A_1, A_3\}$	0.8
		$a_{1,6}, a_{3,8}$ (R)	1	$\{A_1, A_3\}$	0.8
		$a_{3,3}, a_{1,6}$ (S)	1		
		$a_{1,1}, a_{1,6}$ (S)	1	$\{A_1\}$	0.8
		$a_{3,3}, a_{3,8}$ (S)	1	$\{A_3\}$	0.8
		$a_{1,1}, a_{3,3}, a_{1,6}$ (S)	2		
		$a_{3,3}, a_{1,6}, a_{3,8}$ (S)	2		
		$a_{1,1}, a_{3,3}, a_{1,6}, a_{3,8}$ (S)	3	$\{A_1, A_3\}$	2.4
0.2	H_2	$a_{2,2}, b_{1,4}$ (M)	1	$\{A_2, B_1\}$	0.2
		$a_{2,2}, c_{2,10}$ (M)	1	$\{A_2, C_2\}$	0.2
		$b_{1,4}, c_{2,10}$ (M)	1	$\{B_1, C_2\}$	0.2
		$a_{2,2}, b_{1,4}, c_{2,10}$ (M)	2	$\{A_2, B_1, C_2\}$	0.4

FIG. 10B

coallocation set	accumulated miss reduction	normalized miss reduction
$\{A_1, A_3\}$ (S)	2.4	0.86
$\{A_1, A_3\}$ (R)	1.6	0.57
$\{A_1\}$ (S)	0.8	0.29
$\{A_3\}$ (S)	0.8	0.29
$\{A_2, B_1\}$ (M)	0.2	0.07
$\{A_2, C_2\}$ (M)	0.2	0.07
$\{B_1, C_2\}$ (M)	0.2	0.07
$\{A_2, B_1, C_2\}$ (M)	0.4	0.14

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FIG. 10C

method	site(s)	field set packing	mr
(R)	A	$\{A_1, A_3\}, \{A_2\}$	0.57
(S)	A	$\{A_1, A_3\}, \{A_2\}$	0.86
(M)	A, B	$\{A_2, B_1\}, \{A_1, A_3, B_2\}$	0.07
(M)	A, C	$\{A_2, C_2\}, \{A_1, A_3, C_1\}$	0.07
(M)	B, C	$\{B_1, C_2\}, \{B_2, C_1\}$	0.07
(M)	A, B, C	$\{A_2, B_1, C_2\}, \{A_1, A_3, B_2, C_1\}$	0.14

FIG. 10D

method	set packing	mr
r	A	0.57
s	A	0.86
m	A, B, C	0.14
s V m	split A, merge B, C	0.93

FIG. 10E

s V m layout

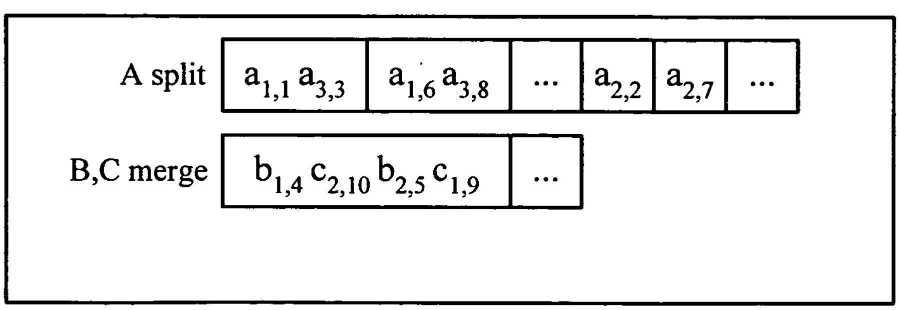

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FIG. 11

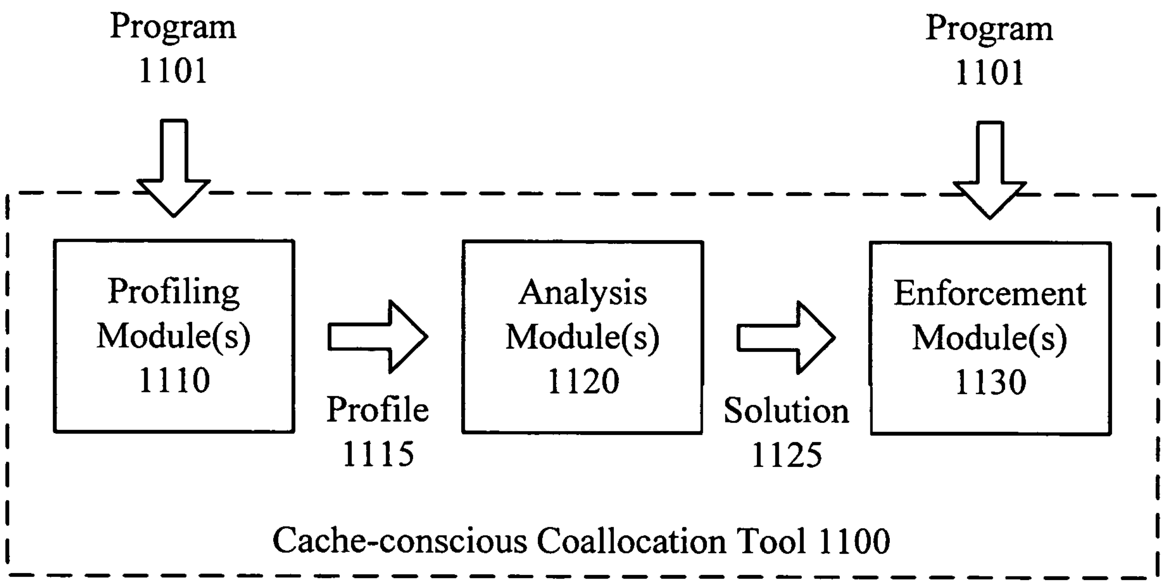

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FIG. 12A

bench-mark	input	# refs	abstraction	# addr	# streams	% hot ref	%hot addr
boxsim	-n 20 -s 1	34580784	object	44635	325	90.83	0.13
			field	295550	3255	85.70	0.56
twolf	test	39299577	object	9447	2906	87.40	6.11
			field	15373	7376	87.84	19.83
vpr	test	91417261	object	3884	986	97.99	4.20
			field	18810	6327	95.04	29.96
mcf	test	24326874	object	55	90	99.96	7.27
			field	19466	2975	84.35	21.95
mst	-t 1000	16332568	object	1001058	7014	58.25	0.20
			field	1255059	5389	24.23	0.32
health	4 2000	176371104	object	172014	66166	94.40	53.83
			field	574638	80354	90.79	22.85

FIG. 12B

bench-mark	sites	hot	object	reorder	merge	split	split or merge	split and merge	field hot	field sites
boxsim	83	24	16	14	17	21	23	24 (109)	131	516
twolf	141	27	24	7	15	13	19	19 (57)	69	200
vpr	54	19	14	6	10	6	10	10 (26)	36	74
mcf	10	4	2	1	1	3	3	2 (11)	16	24
mst	13	5	2	2	3	5	5	5 (13)	14	19
health	11	3	2	2	3	3	3	3 (10)	13	40

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FIG. 12C

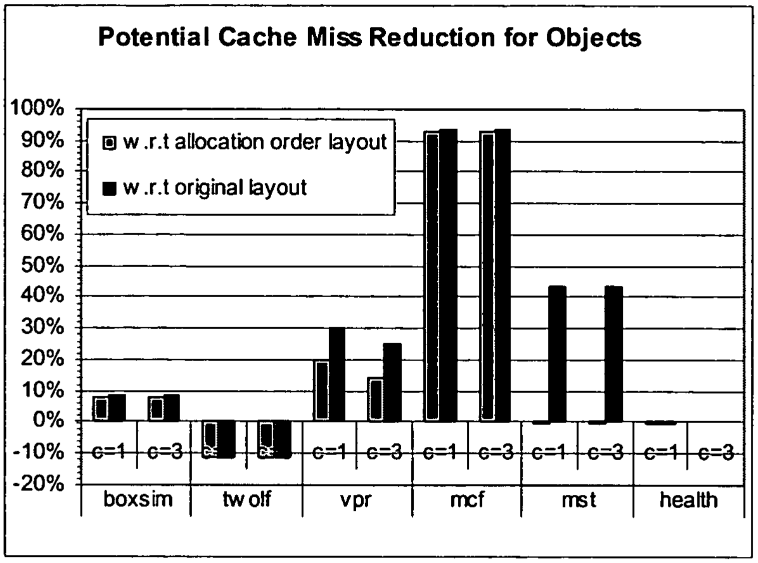

FIG. 12D

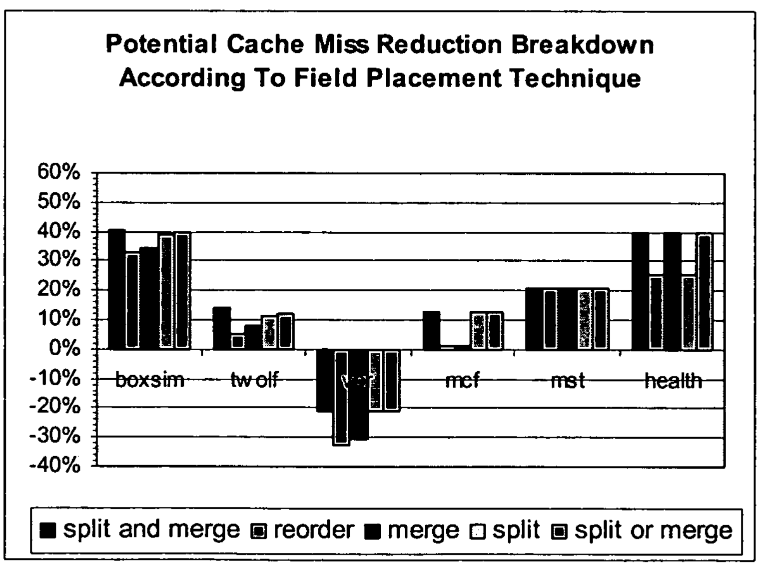

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FIG. 12E

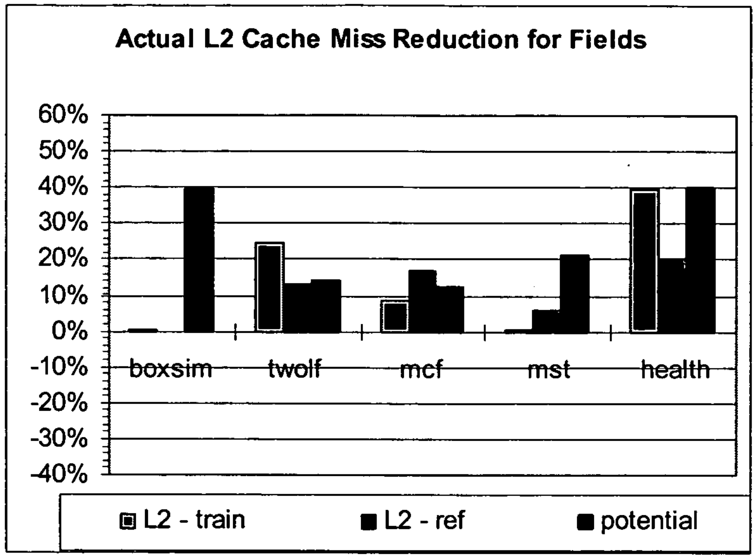

FIG. 12F